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(MURI 97) INTEGRATED COGNITIVE, COMPUTATIONAL AND BIOLOGICAL ASSESSMENT OF WORKLOAD IN DECISION MAKING

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13. ABSTRACT *(Maximum 200 words)*
The project research is completed. Several manuscripts are still in the process of being prepared for publicaiton. The project has developed paradigms to study high-level, high-demand cognitive tasks with fMRI. The project has discovered a surprising phenomenon regarding a mutual constraint on the total amount of cortical activation possible in a dual task situation. The project has determined the effects of input modality in dual tasking. The project has developed an experimental control system (CogLab NT) that will enable future fMRI investigation of the performance of dynamic tasks with some of the critical properties of high-information-load STE's. The project has developed paradigms to study high-level, high-demand dynamic cognitive tasks behaviorally. The project has developed brain-based measures of cognitive workload. The project has dveloped a theory of learning in dynamic decision environments, called Instance-Based Learning Theory (IBLT).

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Air Force Office of Scientific Research

Final Report

August 2003

TITLE: Integrated Cognitive, Computational and Biological Assessment of Workload in Decision Making			
GRANT NUMBER	F49620-97-1-0368		
Duration of study: 5/15/97 – 4/30/02			
PRINCIPAL INVESTIGATOR(S): Marcel Adam Just, Ph.D.			
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Excerpt from Original Project Abstract, describing only the funded parts of the project

The proposed projects focus on the measurement of cognitive workload and the task conditions that lead to it in synthetic task environments (STE's) adapted from DoD labs, in combination with other synthetic tasks that have been psychometrically validated with performance in real-world decision-making environments (e.g. 911 operators, air traffic control tasks, real-time resource allocation in complex mail sorting environment). The research concentration areas of the program include cognitive workload measurement, cognitive modeling and task analysis. The disciplinary approaches that will be integrated include: psychological science, computational modeling, neuroscience (functional brain imaging).

The proposed program includes four research projects that address the nature and impact of cognitive workload on complex, real-time decision-making, each addressing several of the research concentration areas.

Project 1: Neuroimaging of Cognitive Workload during Decision Making
Project 3: Adaptation in Real-Time Dynamic Decision Making

The research approaches include: (a) the use of STE's developed by DoD labs or tasks that have been validated against real-world complex decision making, (b) the development of task analyses to characterize the STE's, (c) collecting detailed process tracing data (information search, eye tracking, keystroke logs, timing of decisions, verbal protocols to learn about decision heuristics), (d) the use of personnel classification tests to investigate individual differences in decision making under workload, (e) the use of biological and neurological (brain imaging) measures of workload effects, and (f) cognitive modeling of information search strategies and decision heuristics.

2. Objectives:

Project 1: Neuroimaging of Cognitive Workload during Decision Making
1. To discover attributes of brain function that are indices of cognitive workload
2. To develop quantitative, automated measures of relevant brain activation attributes
3. To develop a theory and computational model that links the cognitive and cortical levels

[There is no Project 2]

Project 3: Adaptation in Real-Time Dynamic Decision Making
1. To develop a theory of adaptation for individuals working in real-time dynamic decision making (DDM) tasks. The theory should be able to predict and explain:
- the effects of workload in DDM in the short and long term.
- the learning process in DDM tasks

3. Status of Effort:

The project research is completed. Several manuscripts are still in the process of being prepared for publication.

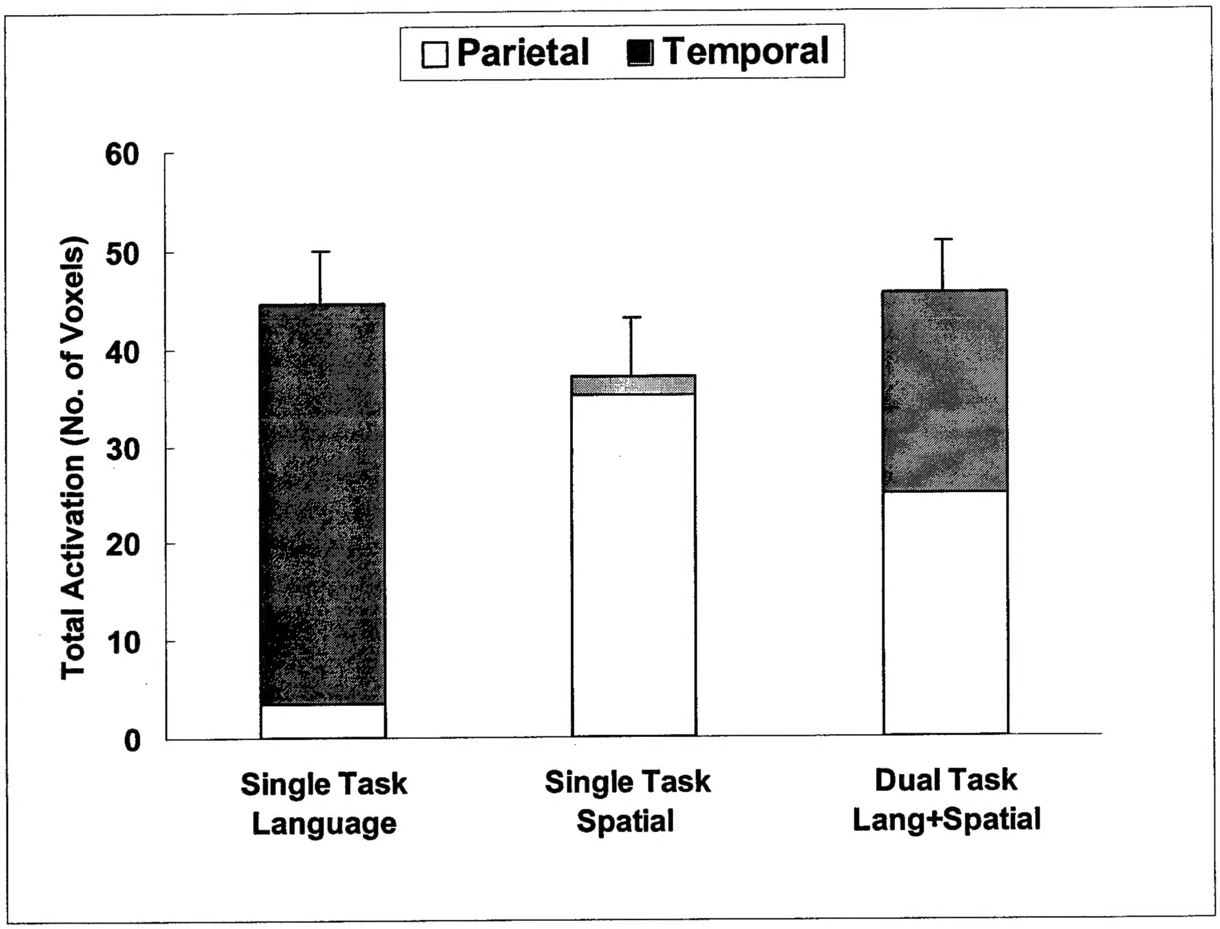
4. Accomplishments/New Findings:

- The project has developed paradigms to study high-level, high-demand cognitive tasks with fMRI.
- The project has discovered a surprising phenomenon regarding a mutual constraint on the total amount of cortical activation possible in a dual task situation.
- The project has determined the effects of input modality in dual tasking.
- The project has developed an experimental control system (CogLab NT) that will enable future fMRI investigation of the performance of dynamic tasks with some of the critical properties of high-information-load STE's.
- The project has developed paradigms to study high-level, high-demand dynamic cognitive tasks behaviorally.
- The project has developed brain-based measures of cognitive workload.
- The project has developed a theory of learning in dynamic decision environments, called Instance-Based Learning Theory (IBLT).

Project 1 narrative: Neuroimaging of Cognitive Workload during Decision Making

Project 1 developed processing models and analytic methods in the context of brain imaging studies of dual task performance. These were particular kinds of dual tasks, namely two high-level tasks that were being performed concurrently, rather than by rapidly switching attention between two tasks. The prototype paradigm required participants to listen to sentences and judge them as true or false while simultaneously performing a mental rotation task, to judge whether one complex 3-dimension object could be rotated into another. The two tasks used different input modalities and a different response apparatus. The paradigm was adapted from the Multi Attribute Test (MAT). The intent was to focus the resource competition on the high-level cognition.

Decreased brain activation in concurrent task performance. The most important empirical outcome was that there was much less brain activation associated with a task when it was one of two dual tasks than when it was being performed alone. This was a major scientific contribution and with considerable practical implications. The scientific article was published in *NeuroImage*, and was also featured in an article in the *New York Times* and many other newspapers and periodicals. The most widely-discussed implication of the study is that cell phone use (the engagement in conversation, not the dialing) during driving might decrease the activation associated with driving. More generally, the results suggest that the bottleneck in high level concurrent task performance is a limitation on brain resources for cognition.



The mean number of voxels activated in each of the two single-task conditions and in the dual condition, in the language areas (left and right superior temporal gyrus, cross-hatched bars) and in the spatial processing areas (left and right parietal lobule, open bars) (and standard errors of the means over 18 participants).

Other bottlenecks can occur in addition, both in input and output, but those bottlenecks can in principle be circumvented. The bottleneck on central resources for cognition cannot be avoided by re-designing the task environment. The only hope for overcoming this central bottleneck is to make the task performance in the two component tasks less demanding of resources.

Temporal relations between two concurrent tasks. Two studies examined the importance of the precise temporal relations between the cognitive demands in the two concurrent tasks. One study made the peak demands in the two tasks occur at the same time (placing the two tasks in phase with each other) versus out of phase with each other. Having the two tasks out of phase was more beneficial, in that there was more

brain activation for each of the component tasks in the out-of-phase condition. This finding shows that the limitation on central cognitive resources is time sensitive, and a time-shift of even a few seconds can ameliorate the concurrent processing situation. (Of course, in some dynamic tasks, such as high-speed driving, such time-shifting is generally not possible. In that case, it is all the more important to time-shift a secondary task whose execution time is less critical).

A second study in this area examined the temporal relations in more detail, to determine the effect of the onset of a second task during the performance of a first task. The two tasks involved were listening to a single sentence (a more automatic task) and performing a single mental rotation task item (a more controlled and less automatic task). The onset of the two stimuli differed by 2 sec. The finding was that it requires more brain work to interrupt the more automatic task. The frontal executive system (DLPFC) showed greater activation for the Sentence first condition than for the Rotation first condition. The manuscript describing this study is being prepared for publication.

Stimulus saliency in dual visual tasks. One of the studies examined how the relative visual saliency of two superimposed stimuli determined the brain response to each of the components. The processing of two superimposed visual stimuli is a little like viewing a head-up display superimposed on a windshield view. The experiment manipulated the relative contrast (and hence saliency) of the two superimposed stimuli. One of the stimuli was a picture of a house and the other was a picture of a face. The reason for superimposing these particular types of stimuli is that the brain response to each one alone is fairly well known. Our new study showed that the amount of activation in each brain area varies with the relative amount of contrast (visual saliency) of the each of the stimuli. For example, there is an area in the fusiform cortex that typically responds strongly to a picture of a face. If a person is viewing a face-house superimposition, then the activation response in the fusiform area is proportional to the visual saliency of the face in the superimposition. Thus the brain response in this dual stimulus situation is governed in part by their relative saliency in the display. An engineered system could determine the brain response to one component of a superimposed display by varying its relative contrast. The manuscript describing this study is being prepared for publication.

Strategic control over brain resource allocation. One study asked the participants to differentially allocate their attention to two concurrent tasks, under their own strategic control. The two tasks involved were listening to a single sentence (a more automatic task) and performing a single mental rotation task item (a more controlled and less automatic task). The most general result was that there was some ability to allocate control brain resources under strategic control, but the size of the effect was modest, having about a 25% impact on the amount of brain activation difference between trying to give a task major attention versus secondary attention. A more specific result was that there was a greater ability to control the brain resource allocation for the less automatic task (rotation) than for the automatic task (sentence listening). That is, it is difficult to get one's brain to stop processing an incoming sentence. Trying to "gate out" a spoken sentence has relatively little effect on the brain activation associated with the sentence processing (particularly in the left posterior temporal area (roughly Wernicke's area) and in the primary auditory cortex (Heschl's gyrus)). By contrast, one can ignore an effortful task like mental rotation. These findings indicate that due consideration should be given to what sights and sounds a computer interface presents in a decision-making situation. Presenting a stimulus that is processed automatically initiates a near-mandatory processing.

Effects of training in dual tasks. One of the brain imaging studies contrasted two forms of training that should make the processing more automatic. The training was either on the two tasks performed alone (individual task training) or on the two tasks performed simultaneously (dual task training). The outcome was similar for the two types of training.

Planning in a problem-solving task. A series of brain imaging studies examined the decision-making processes in a puzzle task called the Tower of London. A distinguishing property of this task is that all of the moves (up to 6, in our studies) have to be planned in advance to ensure that they conclude in a shortest-path solution. One of the main results was the difference in cortical activation between the planning of easier versus harder problems. The simpler problems required the planning of fewer moves (2-3) whereas the harder problems required the planning of 4-6 moves. (The problems with more moves typically entail the setting of subgoals). For the simpler problems, the cortical control produced parietal activation, whereas the harder problems produced additional frontal (DLPFC) activation. The significance of this finding is that simpler decisions can be made on the basis of a perceptual analysis, whereas the more complex decisions require the clear involvement of a prefrontal cortex planning capability. This finding reflects the more general view of the cortical system as dynamically adapting to the task demands as they arise. That is, the cortical centers are activated on an as-needed basis, a dynamic resource-allocation system for neural resources. A computational model for this task provided a precise account for the behavioral and brain imaging results. Some of the outcomes of the project have appeared in *Neuropsychologia*. (This project was also supported in part by ONR).

Summary of empirical findings. The project started out by developing new STE's (synthetic task environments) suitable for investigating dynamic decision making, including the development of software, hardware, and new data processing techniques, for both brain imaging and behavioral studies. This new research infrastructure was then put to use into investigating various facets of dynamic decision-making

The results suggest that there is an upper limit on the total amount of cortical activation that can be supported at one time. This corresponds to the difficulty in fully attending to two streams of thought at one time. But the phenomenon is better described as a resource constraint.

This new interpretation has several interesting implications. First, it suggests that perhaps two streams of thought could be attended if they one or both of them were undemanding. Consistent with this view, driving and conversing can come to be co-performed as driving skills become automated and less resource demanding than they are in a novice driver. A second implication is that extensive training may automate performance of two tasks sufficiently to make them co-performable. However, even for an experienced driver, a complex and rapidly changing traffic situation can put an end to conversation, so training probably is a relative rather than an absolute solution.

Cognitive workload principles emerging from Project 1. The research has enabled the development and refinement of the following principles of cognitive workload

- performance is capacity-constrained
- attention is allocated dynamically
- in a given task, activation is distributed in the brain in 10-20 discrete centers
- there are individual differences in performance (beyond storage and processing speed), predicted by psychometric test scores
- Task requirements (time course of load) determine level of performance and rate of learning

Project 3 narrative: Adaptation in Real-Time Dynamic Decision Making

The three major products of this research were:

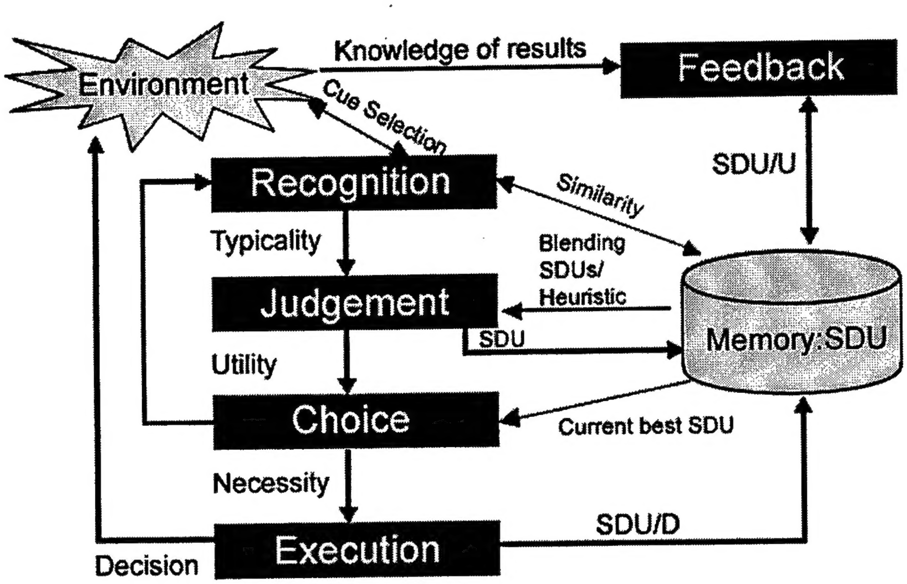
- a set of Synthetic Task Environments (STEs) used as tools for research DDM tasks
- results from two major experiments to test the effects of workload and pace of learning in DDM

- a theory of learning in dynamic, complex situations, developed using computational/cognitive modeling.

Three STEs (Synthetic Task Environments) were developed and used in this research. The first STE is an Automated Mail Sorting Task (AMST) developed from real world observations in the US Post Office (Lerch and Harter, 2001). The second STE is an isomorph of AMST that is more flexible, and it provides the experimenter with multiple manipulations and definitions of scenarios. This is called the Water Purification Plant (WPP), a task that presents many advantages over other STEs or "Microworlds" used in the study of DDM. A summary of DDM STEs and the criteria for comparison is presented in (Gonzalez and Vanyukov, submitted). The third STE was a Multi-Attribute Task (MAT) Battery simulation, originally developed at NASA by Comstock and Arnegard (1992), but adapted to work with WPP.

Two main experiments using WPP and WPP with MAT demonstrated detrimental effects of task workload. Workload was manipulated as time pressure and multitasking (Gonzalez (a) in Press; and Gonzalez (b), under review). The experiments showed that task workload interacts with the inherent human cognitive abilities to produce different learning curves. Task workload produces negative effects on learning more pronouncedly for individuals with low fluid intelligence. Time pressure produces poor performance for individuals who practice under time constraints regardless the length of practice they are given. That is, best learning occurs only when individuals practice with no time constraints. Time constraints limit individuals to generate alternatives, produce poor exploration of the environment and therefore, poor learning in the long term. Further, we analyzed micro-behavior, comparing individual's behavior to pre-defined simple heuristics. We found that people follow different strategies under workload. Particularly, individuals with low cognitive abilities and under time pressure follow heuristics increasingly over time, while individuals with high cognitive abilities or any individual under low workload reduce their use of heuristics over time. The reduction of the use of simple heuristics is associated with best performance. This indicates that individuals learn to use the knowledge acquired in the context of the task, and that taking advantage of this knowledge leads them to best performance.

Using cognitive modeling with ACT-R, we developed a new theory of decision making in dynamic environments (Gonzalez, Lerch, and Lebiere, 2003). This new theory is called Instance Based Learning Theory (IBLT). Traditionally, decision making has been studied under two groups: Judgment and Choice. Often, decision making theories do not apply to real-world decision making. In the real world, decision making is dynamic. Decisions made today change the situations considered to make decisions tomorrow, and the environment changes independently of the user's actions. IBLT extends the traditional view of decision making including the process of recognition, feedback, and separating the choice from its execution. The figure to the left shows this process.



IBLT relies of several learning principles. One particular principle is that, individuals store

instances composed of three elements: the decision making situation, the decision and the utility of the decision. The IBLT process suggests that these pieces of knowledge develop over time and are retrieved when future decisions are made.

IBLT emerged from the process of doing a cognitive model of decision making in WPP. Observations, Verbal protocols (Gonzalez, in press), and the previously presented empirical studies led us to a process that we could implement in a cognitive theory ACT-R. The model's data compared to human data. In particular, the learning mechanisms proposed in IBLT were tested against human data. Some of the findings are that: decision makers acquire decision instances with practice in the task; instance-based decision-making does not rely on one particular previous instance, but rather on a blending or accumulation of instances from the past; decision makers do not directly respond to the feedback in the task, relying more on the recognition process to learn.

Framing effects in decision making. We developed a new paradigm for studying a classical decision making task using brain imaging to measure cognitive workload. The study examined the neural basis for the ubiquitous finding concerning the framing effect in the choice between risky and certain outcomes. The framing effect shows that a description of a problem in positive (gains) versus negative (losses) terms, systematically affects the risk attitude, even though the logic of the problem is identical in the two statements. For example, a positive statement might describe a medical policy decision in terms of how many lives are saved as a result of one choice, whereas a negative statement would describe the same situation in terms of how many lives are lost as a result of the other choice. People consistently are risk-averse for gains and risk-seeking for losses. The framing effect has previously been explained through an appeal to economic theories. But rarely has the underlying cognitive mechanism been examined. This project made an important new contribution to understanding this decision-making process by showing that it is not the difference between the positive and negative frames that elicits different brain activity. Rather, it is the choice (certain or risky outcome) that elicits different brain activity. Risk aversion in gains manifests itself as significantly higher amounts of brain activity (in frontal and parietal areas) in risky compared to certain responses. Risk seeking in losses manifests itself as similarly high brain activity in both risky and certain responses. That is, when people evaluate losses, both the certain and the risky outcomes involve similar brain activity in frontal and parietal areas. But when they evaluate gains, the risky outcomes elicit significantly higher activity than the certain outcomes. The work has been written up and submitted for publication (Gonzalez, Dana, Koshino, Just, submitted for publication).

Summary of Empirical Findings

- Individuals under high time constraints will learn poorly compared to individuals under low time constraints, regardless the amount of practice.
- Under high workload individuals have more difficulty acquiring and refining decision instances. Less and less diverse instances limit learning.
- Cognitive capacity interacts with the cognitive workload. Individuals with low cognitive capacity and under high cognitive workload have more difficulties to learn. The same individuals under low cognitive workload have more time to acquire and refine the task knowledge.
- With learning individuals gradually switch from rule-based to instance-based performance.
- Cognitive modeling makes the instance-based description of the decision-making precise and dynamic
- Differential brain activity appears for risky and certain choices. More brain activity in parietal and frontal areas is related to risky choices related to gains.

REFERENCES

Comstock, J. R., & Arnegard, R. J. (1992). The multi-attribute task battery for human operator workload and strategic behavior research, NASA Technical Memorandum 10417 (pp. 1-29).

Gonzalez, C. and Vanyukov, P. "Use of MicroWorlds To Study The Psychology of Dynamic Decision Making", Submitted.

Gonzalez, C. Learning to Make Decisions in Dynamic Environments: Effects of Time Constraints and Cognitive Abilities. Human Factors. In Press.

Gonzalez, C. Decision Making in a Dynamic, Real-Time Environment: Learning under High Cognitive Workload. Under Review

Gonzalez, C. (2003). *Novice and expert verbal protocols in real-time dynamic decision-making*. Denver, Co. Proceedings of the Human Factors and Ergonomics Society.

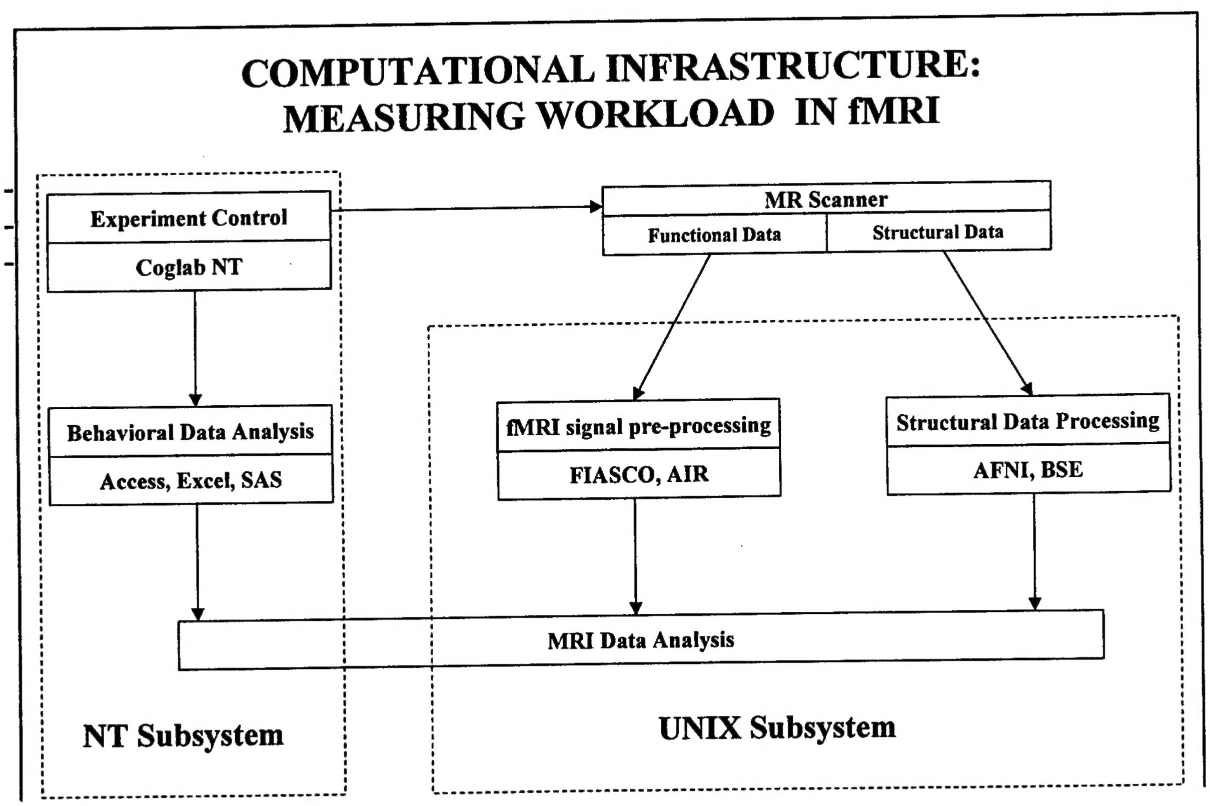
Gonzalez, C., Lerch, F. J., & Lebiere, C. (2003). Instance-Based Learning in Real-Time Dynamic Decision Making. *Cognitive Science, 27*, 591-635.

Lerch, J.F and Harter D. E. "Cognitive Support for Real-Time Dynamic Decision Making" Information Systems Research, INFORMS, Vol. 12, No. 1, March 2001, pp. 63-82

Technical development

One large initial success was in creating a paradigm for studying concurrent task processing in an MRI scanner. The paradigm required the coordination of MRI-compatible earphones with a visual display. A special MRI-compatible response apparatus was developed. Some specialized equipment was built and some of it was purchased. Specialized software was developed for controlling two high level tasks concurrently. Finally, the two tasks were designed so that it was possible to perform them concurrently, with resource competition focused at the level of central resources.

One of the main software development accomplishments was an experimental control system (CogLab NT) for running high-level cognitive tasks, synchronized with and MRI scanner. A related accomplishment was the construction of an integrated system of about 8 software systems to underpin the cognitive brain imaging research.



CogLab NT controls the running of an experiment under Windows NT or Windows 2000 and it provides flexible experiment design.

- The program is capable of presenting a variety of stimuli, including text, images, and sounds.
- An experiment can be of "blocked" or "single-item" design, with a pre-defined sequence of events or self-paced, etc.
- It also records subject's responses and synchronizing pulses from the MR scanner.

To assess the volume of cortical activation in a given brain center, we developed a system for defining anatomical regions of interest (ROI), and then measured the activation within each independently (anatomically) defined region, using a previously established parcellation scheme. We developed supporting software that helped with:

- Coregistration of structural (anatomical) and functional (activation) data
- BSE (Brain Surface Extraction), stripping away the image of the skull, leaving only the brain
- Transformation into standard (Talairach) space

The project developed software **(Voxcount)** for measuring **volumetric indices of brain activation**.

- Number of activated voxels per ROI (region)
- % signal intensity change for active voxels.

An additional program measured some of the **dynamics of the brain activity (Voxcor)**

- correlation between the time series of the activation in two areas as an estimate of functional connectivity.
- Functional connectivity increases with cognitive workload
- Time courses of active voxels in different areas.

These programs were integrated with other software tools that are widely available. The value added of this project's software contribution is that they enabled the measurement of cognitive workload, and not just locations of brain activations.

In summary, the project helped determine the how variations in cognitive workload impacted on real-time synthetic task environments entailing decision-making. Fine grained measures of performance, strategy assessments, task analysis, and cognitive modeling were developed to provide a broad-ranging account of cognitive workload in these situations. The workload measures are both behavioral and biological (brain imaging-based). Software and hardware for the synthetic task environments enable continuing research on high-information-load tasks of real-world relevance.

5. Personnel supported (not necessarily full-time)

Marcel Just	PI
Patricia Carpenter	co-PI
F. Javier Lerch	Project Leader
Cleotilde Gonzalez	Project Leader
Tim Keller	Postdoctoral Associate
Robert Mason	Postdoctoral Associate

Alice McEleney	Postdoctoral Associate
Sharlene Newman	Postdoctoral Associate
Erik Reichle	Postdoctoral Associate
Donald E. Harter	Doctoral student
Huilong Wu	Doctoral student

6. Publications supported by the grant:

Just, M. A., Carpenter, P. A., Keller, T. A., Emery, L., Zajac, H., & Thulborn, K. R. (2001). Interdependence of non-overlapping cortical systems in dual cognitive tasks. *NeuroImage, 14,* 417-426.

Newman, S. D., Carpenter, P. A., Varma, S., & Just, M. A. (2003). Frontal and parietal participation in problem solving in the Tower of London: fMRI and computational modeling of planning and high-level perception. *Neuropsychologia, 41*, 1668-1682.

Gonzalez, C., Lerch, F. J., & Lebiere, C. (2003). Instance-Based Learning in Real-Time Dynamic Decision Making. *Cognitive Science, 27*, 591-635.

Gonzalez, C, Learning to Make Decisions in Dynamic Environments: Effects of Time Constraints and Cognitive Abilities. *Human Factors*. In Press.

Gonzalez, C. (2003). Novice and expert verbal protocols in real-time dynamic decision-making. Denver, Co. *Proceedings of the Human Factors and Ergonomics Society.*

Submitted Manuscripts:

Kravitz, D. J., & Just, M. A. Distributed cortical activity in object recognition: Graded activation along a house/face continuum.

McEleney, A., Newman, S. D., Keller, T. A., & Just, M. A. Deductive reasoning and the brain: An fMRI study of conditional reasoning.

Gonzalez, C. & Vanyukov, P. Use of microworlds to study the psychology of dynamic decision making.

Gonzalez, C. Decision making in a dynamic, real-time environment: learning under high cognitive workload.

7. Interactions/Transitions:

a. Presentations:

Invited Presentations

Measuring brain function in high-tech environments: fMRI studies of cognitive workload during real-time dynamic decision making. Invited presentation at the Army War College on the Impact of Technology on the "Physiological and Psychological Dimensions of Warfare" at Georgia Tech, December 9-10, 1997, Atlanta, Georgia.

Cognitive loading and the future military. Invited presentation at the Cognitive Sciences Workshop sponsored by the Science Applications International Corporation (SAIC), January 8-9, 1998, Strategic Assessment Center, McLean, Virginia.

fMRI and the Neuro-architecture of cognition. Invited presentation at the National Institute of Mental Health "Cognitive Neuroimaging Research: Design and Interpretation Meeting", September 13-15, 1998, Rockville, Maryland.

Modeling cognitive systems with artificial intelligence & fMRI. Invited presentation at BrainMap '98: Human Brain Mapping and Modeling, December 7, 1998, San Antonio, Texas.

Other Presentations

Lerch, J., Harter, D., & Gonzalez, C. (1998). Time pressure in real-time dynamic decision making. In the *Proceedings of the Association for Information Systems Conference* (AIS, Americas Conference, 1998), Baltimore, Maryland on August 14-16, 1998.

Lerch, J., Harter, D., & Gonzalez, C. (1998). Individual differences in real-time dynamic decision making. In the *Proceedings of the Fourth Conference on Naturalistic Decision Making*, Warrenton, Virginia. May 29-31, 1998.

Gonzalez, C. Instance-Based Decision Making in Dynamic Environments: Modeling the Learning Process. Recognition-Primed Decision Making Workshop. Boulder, CO. October 23, 2001.

Gonzalez, C. Instance-Based Decision Making in Dynamic Environments: Modeling the Learning Process. Computational and Mathematical Organization Theory Conference. CASOS 2001. Pittsburgh, PA. p. 71. July 6, 2001.

Gonzalez C., Lebiere C., and Lerch F.J. ACT-R Learning in a Real-Time Dynamic Decision-Making Task. Proceedings of the *Sixth Annual ACT-R Workshop*. George Mason University. Fairfax, Virginia. August 6-9, 1999.

fMRI and the neuro-architecture of cognition. Symposium held at the Psychonomics Society, November 19-21, 1999, Los Angeles, California.

4CAPS: Cortical Capacity-Constrained Concurrent Activation-based Production System. Presented at the ONR Conference, June 5, 2000, Baltimore, Maryland.

The brain-activation dynamics underlying fluid intelligence. Presented at the 1st Annual Conference of the International Society for Intelligence Research (ISIR), November 30, 2000, Cleveland, Ohio.

fMRI and the neuro-architecture of cognition. Presented at the T. J. Watson IBM Research Center, January 31, 2001, Yorktown Heights, New York.

b. Consultations: The project investigators consulted with Air Force personnel at Wright Patterson AFB (Glenn Wilson) and Brooks AFB San Antonio (Shifflet, Hall, Regian).

c. Transitions: N/A

8. New Discoveries:

The project has discovered a surprising phenomenon regarding an upperbound on cognitive workload during the performance of two concurrent tasks: The total amount of brain activation was approximately similar during the performance of one versus two tasks, indicating that a given task is allocated much less activation if it is being performed concurrently with another task.

9. Honors/Awards:

1997-2002	NIMH Senior Scientist Award
2000	American Association for the Advancement of Science Fellow

MJ notes:

Check on ONR description of TOL task
Check CV for other possible publications
Proofread for sensibility